AN INVESTIGATION OF A MEANS OF DAMPING THE EFFECTS OF A RESONANT INERTIAL LOAD ON THE CONTROL SERVO SYSTEM

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Richard W. Sheppe

Captain, United States Marine Corps

Submitted in partial fulfillment of
the requirements for the degree of

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PREFACE

In a closed loop servomechanism, the load appears as a part of the output transfer function. Any change in the characteristics of the load changes the condition of the servo as a whole, and it is quite possible to cause the entire loop to go into oscillations by sufficient change.

It is possible to improve the destabilizing effects of a resonant load by various methods, one of these being the subject of this investigation.

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1. Scope of the Investigation

The introduction of a by-pass across the actuators of a wing control servo system produces some degree of damping of the resonant inertial load experienced by the system from the actuator outboard through the linkage and including the control surfaces. The amount of damping effected by the by-pass line is a function of the amount of hydraulic fluid which is allowed to pass through the by-pass line. This amount of flow can be controlled by varying the size of an orifice placed in the by-pass line.

The hydraulic servo in this case is one of two control servo systems in the BW-1"Terrier" Missile. For this investigation, the control servo system from the missile is used throughout, with the exception of having the known inertial lead of the wing, wing load, and linkages simulated by a mass connected into the wing sockets of the channel in use.

The introduction of a by-pass line across the actuators of the wing control servo systems produces some degree of damping of the resonant inertial leads experienced by the system from the actuator outboard through the linkages and including the control surfaces.

The amount of damping effected by the by-pass line is a function of the amount of hydraulic fluid which is allowed to pass through the by-pass line. This amount of flow can be controlled by varying the size of an orifice placed in the by-pass line.

2. Servo Loop Components, Functional Description

The general plan of this investigation is to rig a by-pass line in a missile H section, as shown in the schematic, Figure 1. Nyquist and Bode plots will show the effects of changing orifice size with a constant inertial load.

Figure 1 is a schematic of the modified system, showing the by-pass line across the input lines to the actuator from the servo valve. A means of placing the various orifices in the by-pass line was incorporated.

In the actual missile, the actuators, servo valves, and pumps are mounted directly on a rather complex hydraulic manifold in order to save line losses, weight and space.

In order to mount the by-pass line, a special sub-manifold was constructed and bolted between the main manifold and the operating servo valve. Hydraulic lines, capable of withstanding full system pressure (about 2200 psi), were fixed to the sub-manifold and led around an assortment of components to a position where the various orifices could be mounted as conveniently as possible.

The test set-up for this investigation involves the use of the computer and hydraulic sections from a BW-1 Terrier Missile plus various items of test equipment described later.

The computer section of the missile includes the lead network, error limiters, servo amplifier, fixed and floating limiters, gain change amplifier, and the $f_2(t)$ potentiometer.

The hydraulic package contains the servo valves, the wing actuators, flow limiters, and the feedback potentiometers. The wing solenoid is an integral part of the Moog servo valve.

In addition, the f(p) potentiometer located in the nose section provides an additional input to the gain change amplifier.

Together, the computer and hydraulic packages are referred to as a wing corrector channel. There are two wing corrector channels per missile, A and B, each driving a pair of central wings. These channels are shown schematically in Figure 2.

This investigation will concern itself with one corrector channel only. For this reason a discussion of the cross-coupling potentiometer and its effect in the servo loop will be omitted. Similarly, the telemeter potentiometer will also be omitted.

The function of each of the above mentioned components will be mentioned briefly.

Input to the lead network is a changing DC wing signal from the intelligence converter. The lead network causes a phase lead shift of the changing DC wing signal in order to compensate for aerodynamic and servo lag and thereby reduce overshoot and eliminate oscillation about the nutating axis of the guidance radar. See Figure 3.

The error limiters provide control of the signals sent to the servo amplifier so that the servo amplifier does not drive the missile beyond its maneuver capabilities. See Figure 3.

The servo amplifier is a single ended, high gain DC amplifier which accepts signals from the lead and error limiter networks and amplifies them for use in the servo valve.

The servo valve is a two stage valve in which hydraulic pressure is utilized to open and close the valve so that the resultant flow of hydraulic fluid to the actuator is proportional to the current flow from the servo amplifier.

The wing actuator is a double ended hydraulic piston type actuator which converts the hydraulic output of the servo valve into linear motion. Through a mechanical linkage, this linear motion is changed to wing rotation.

The flow limiters, inserted in the cylinder lines, restrict flow in one direction and permit free flow in the opposite direction. Restriction of the return flow from the actuators prevents aerodynamic forces from driving the actuators, resulting in backlash.

The feedback potentiometer is mechanically connected to the pistons of the actuators. The feedback signal, highly linear, is sent to the fixed and floating limiters and thence to the grid of the servo amplifier to complete the feedback loop.

During the guidance phase of flight, a rather large condenser (4 micro farad) is inserted in the feedback path. It is used as an integrating capacitor, with respect to the forward loop, and serves to correct any situation in which a constant error signal might be produced. This constant error signal would result in the missile's failing to close on the radar beam.

The floating limiter is an electronic circuit designed to limit the rate of integration and to prevent any wing response to an input signal caused by radar beam jitter. See Figure 4.

The fixed limiters are also electronic circuits designed to limit the amount of integration resulting from the action of the integrating capacitor. Unlimited integration can result in excessive maneuvers and ultimate structural failure from radical wing positions. See Figure 5.

The wing gain change amplifier serves to change the overall computer and servo loop gain to account for changes in missile velocity, air density and the center of gravity. Inputs to this amplifier are obtained from a potentiometer, f(p), in the nose section, and a potentiometer, $f_2(t)$, in the program timer. In this investigation, the gain change amplifier will be set at a fixed minimum gain value (maximum feed forward gain) in order to remove one variable from the tests. This value will, however, represent the extreme gain condition encountered by the missile and is hence a conservative artificiality.

Detailed descriptions of the above devices are found in OP 2329, Vol.I. Circuitry is shown in the schematics, Figures 3, 4, 5 and 6.

3. Test Procedure

Figure 7 is a schematic of the test equipment actually used. In order to simulate the incoming changing DC wing signal, a Philbrick amplifier with a gain of one is inserted in the feedback loop. Inputs to this amplifier are a sinusoidally oscillating signal of amplitude .250-2.5 volts, and the voltage from the feedback potentiometer of the order of one volt per degree of wing motion.

The potentiometer marked Z, Figure 7 and voltage source arrangement is included so that in the open loop switch position, the wings will not be allowed to drive into the stops.

The input oscillator is a Low Frequency Decade Oscillator by Solartron Laboratory Instruments, Ltd., capable of oscillations from .1 to 11100 cps.

Output is measured with the Resolved Component Indicator by Solartron Laboratory Instruments, Ltd., giving the reference and quadrature components of the output voltages directly.

The gain change amplifier is held at a value of 50 volts throughout the tests by means of a potentiometer to attain minimum feed-back gain.

For open loop measurements, and with the input signal ranging from 20 to 60 cps, a 1 micro farad condenser is inserted in series with the output line to the Solartron equipment, for finer data values. When the input on open loop is 60 cps or higher, this condenser is replaced with a .1 micro farad condenser for the same reason.

The output signal is monitored on the Solartron cathode ray oscilliscope.

4. Results

A series of runs were made using orifice sizes of zero, .020", .040" and .060". Data is presented in the Bode diagram form. Figure 8 shows the open loop amplitude response of the four orifice sizes. Figure 9 shows the open loop phase angle graphs of the four orifice sizes. One run with a zero orifice is included for comparison purposes.

Examination of Figure 9, showing the phase angle curves, shows a positive stabilizing effect of introducing the orifice at lower frequencies. The .020" orifice at low frequencies indicates a destabilizing effect which can perhaps be explained by some unpredicted contribution from the sub-manifold or other component. At higher frequencies definite destabilizing resonant effects have been produced by all but the .060" orifice. Figure 8, the amplitude curves, shows that the .060" orifice has reduced the resonant "hump" at higher frequencies. The .020" and .040" orifices have seemingly introduced non-linearities in the higher frequency range. All orifices indicate a response roughly the same as a zero orifice in the lower frequency spectrum.

Although it is difficult to establish a trend with this limited number of orifice sizes, it is felt that turbulent flow effects are occuring with the orifices in the upper frequency ranges, and more particularly with the smaller sized orifices.

It is felt that non-linear effects of significant magnitude account for the apparently random responses in the upper frequency ranges (700-850 rad./sec.). These effects could be the result of the formation of standing waves in the by-pass line or the inter-

play between the flow through the orifice and the flow limiters in the servo valve-actuator lines, or combinations of these and other phenomenon.

It is further felt, however, that the increased orifice size response (i.e., .060") points to a successful means of stabilizing this system across the entire frequency spectrum encountered in this investigation. Further experiment with larger orifices could prove to be quite interesting. Further, the removal of the flow limiters for a series of tests might prove desirable in the reduction of non-linear effects. Finally, performance of the system with a by-pass actually cut through the manifold of the missile and thereby eliminating the artificialities of the by-pass line and sub-manifold might prove beneficial.

It is felt that because of the introduction of these rather complicated variables some other method of damping would be more encouraging despite the ease with which the production missile could be altered to incorporate an effective orifice and by-pass.

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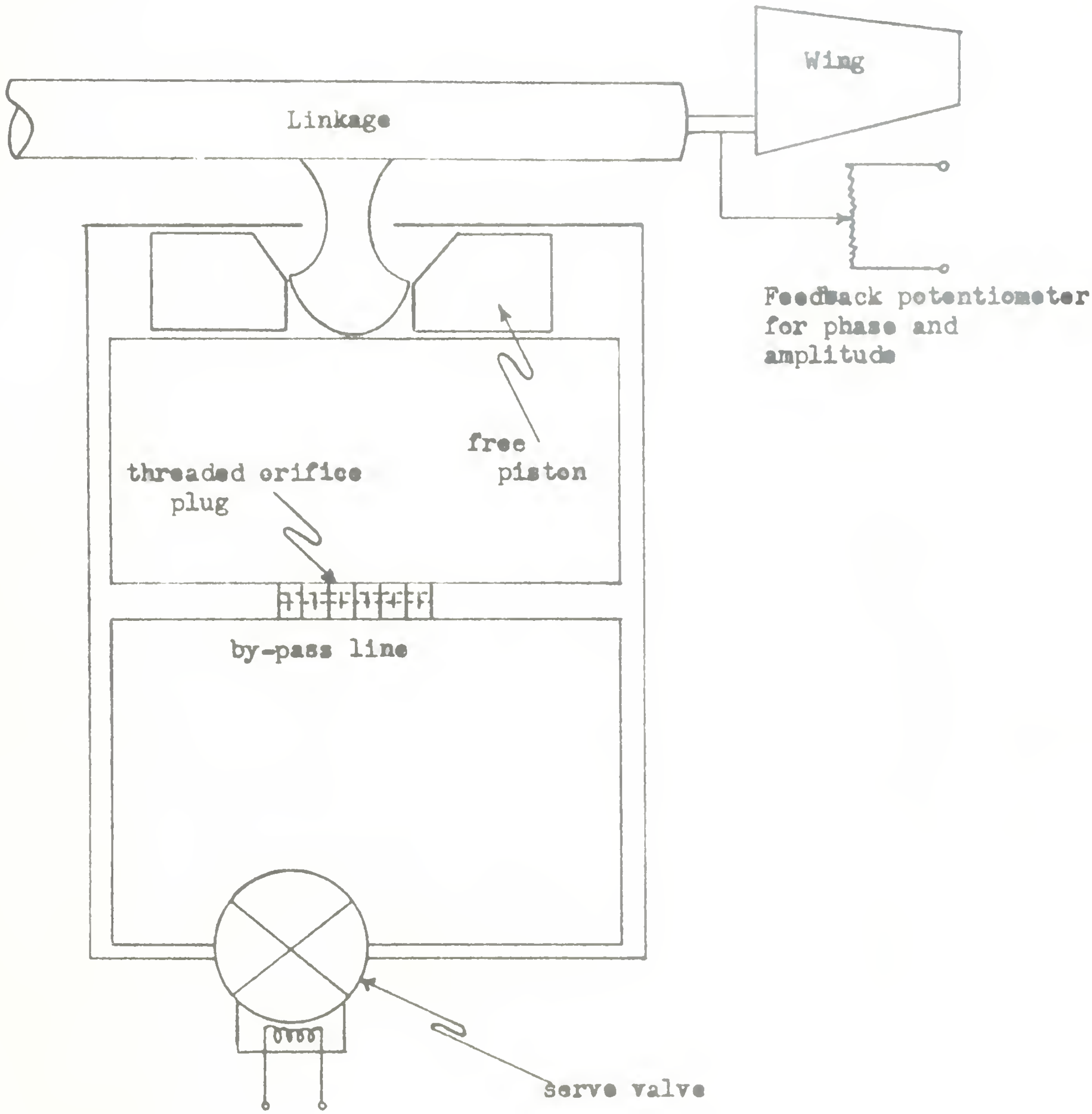


Fig.1 Schematic of H-section modification

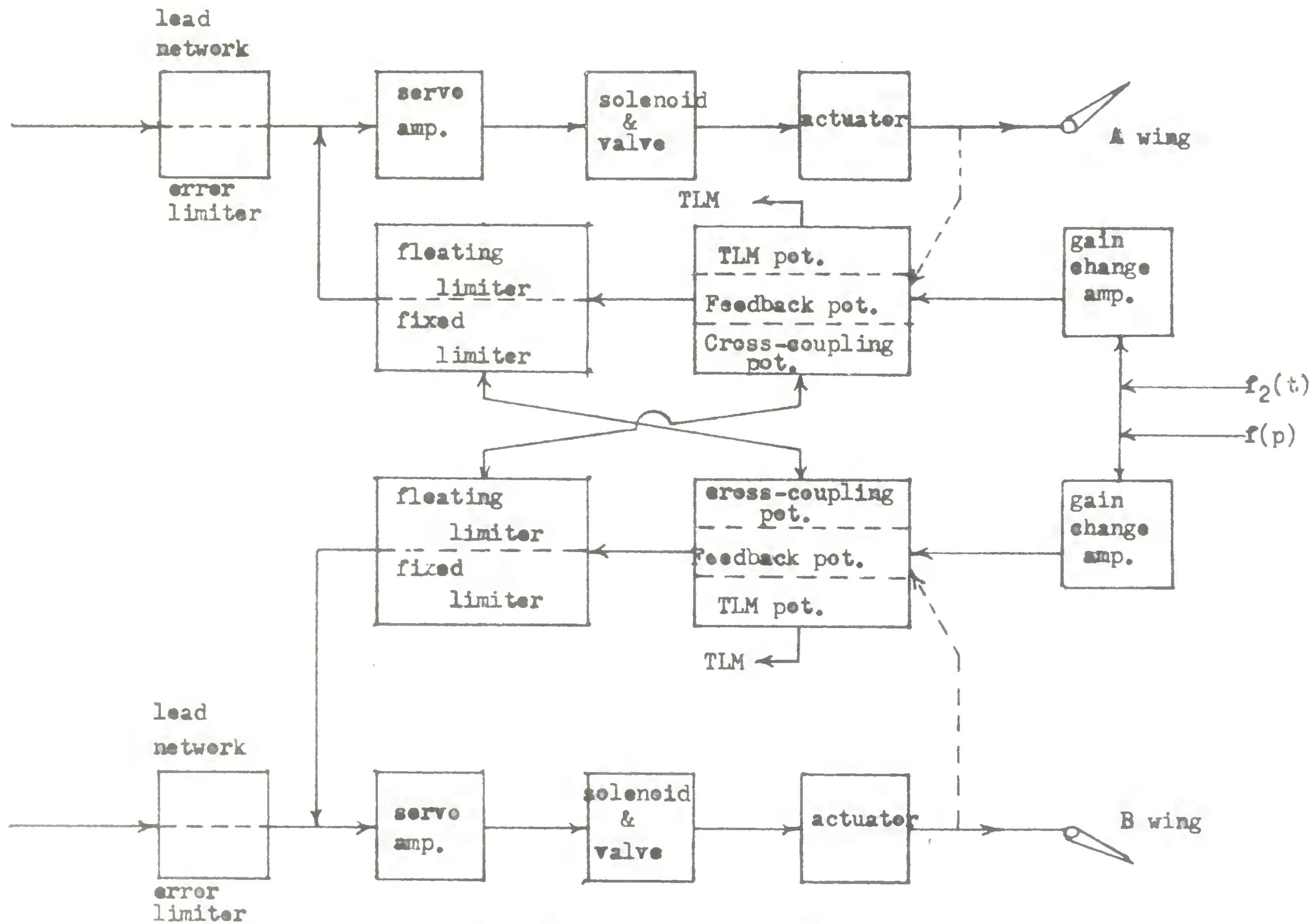


Fig.2. Computer block diagram

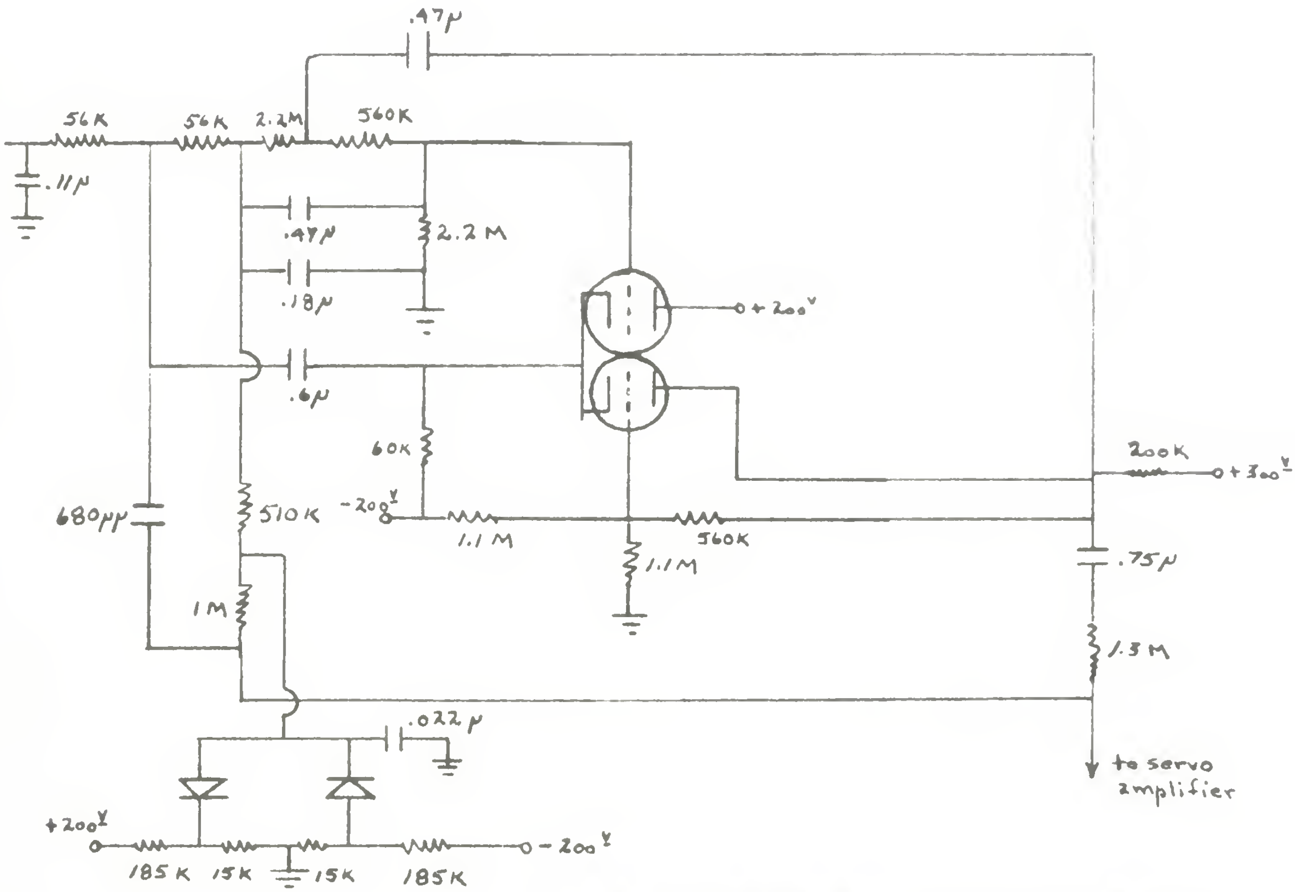


Fig 3 . Lead Network and Error Limiter

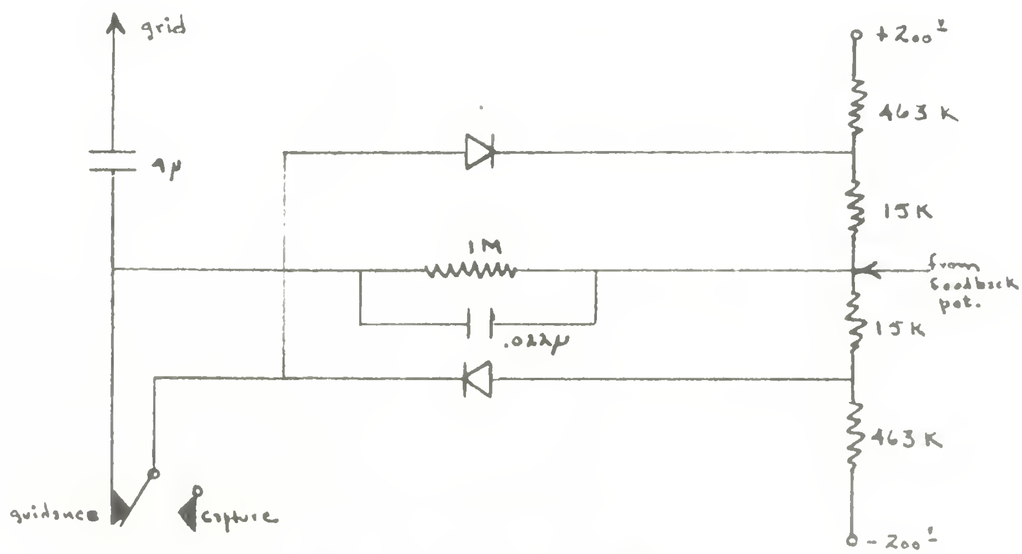


Fig.4. Floating Limiter

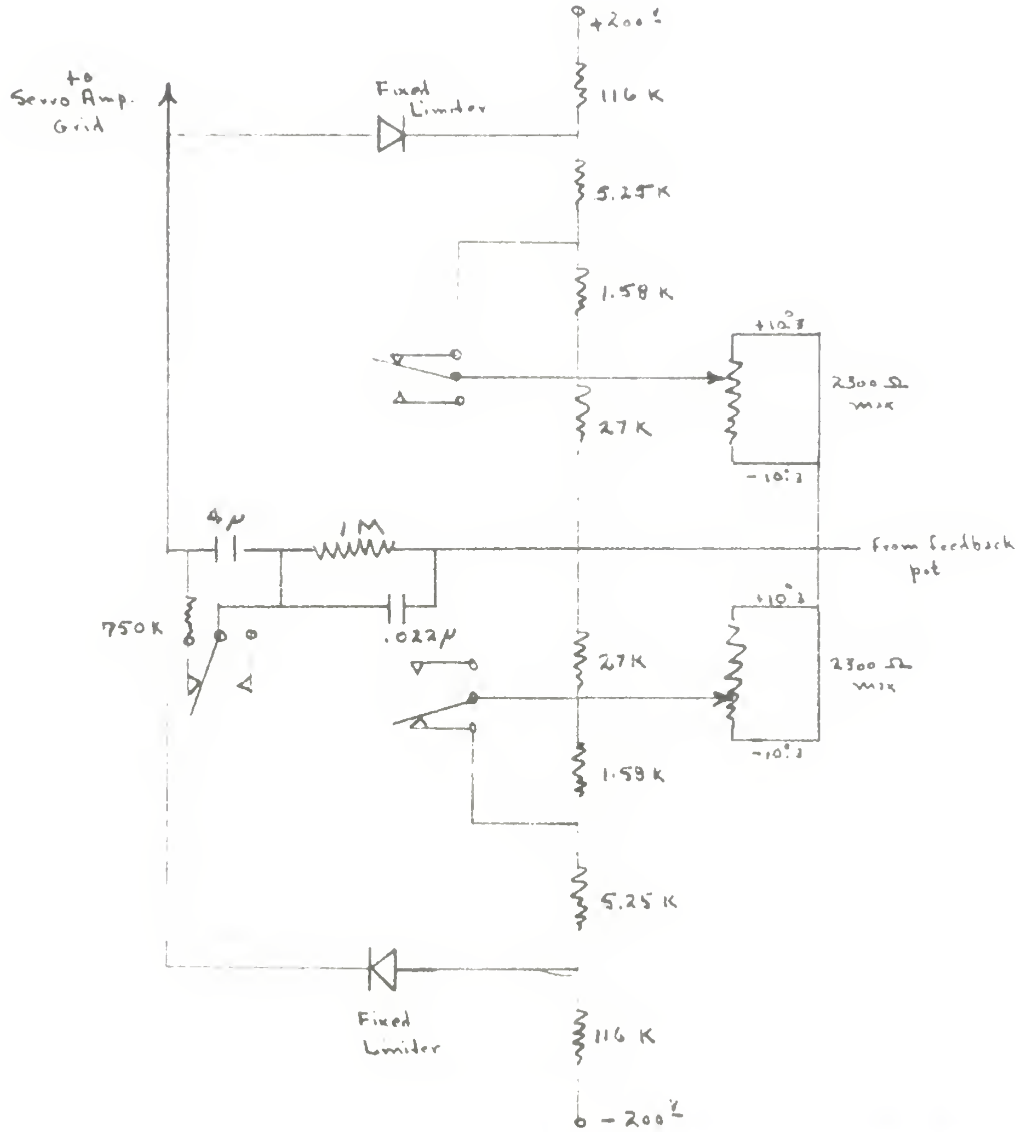


Fig. 5. Fixed Limiters (and cross-coupling potentiometers)

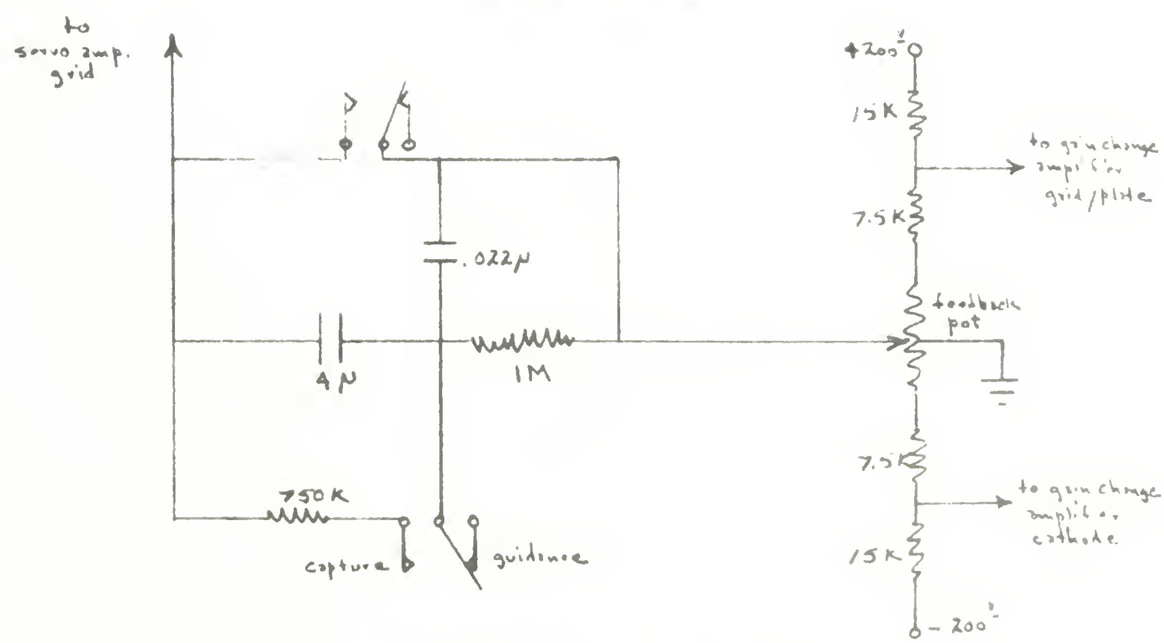


Fig.6 . Feedback loop simplified

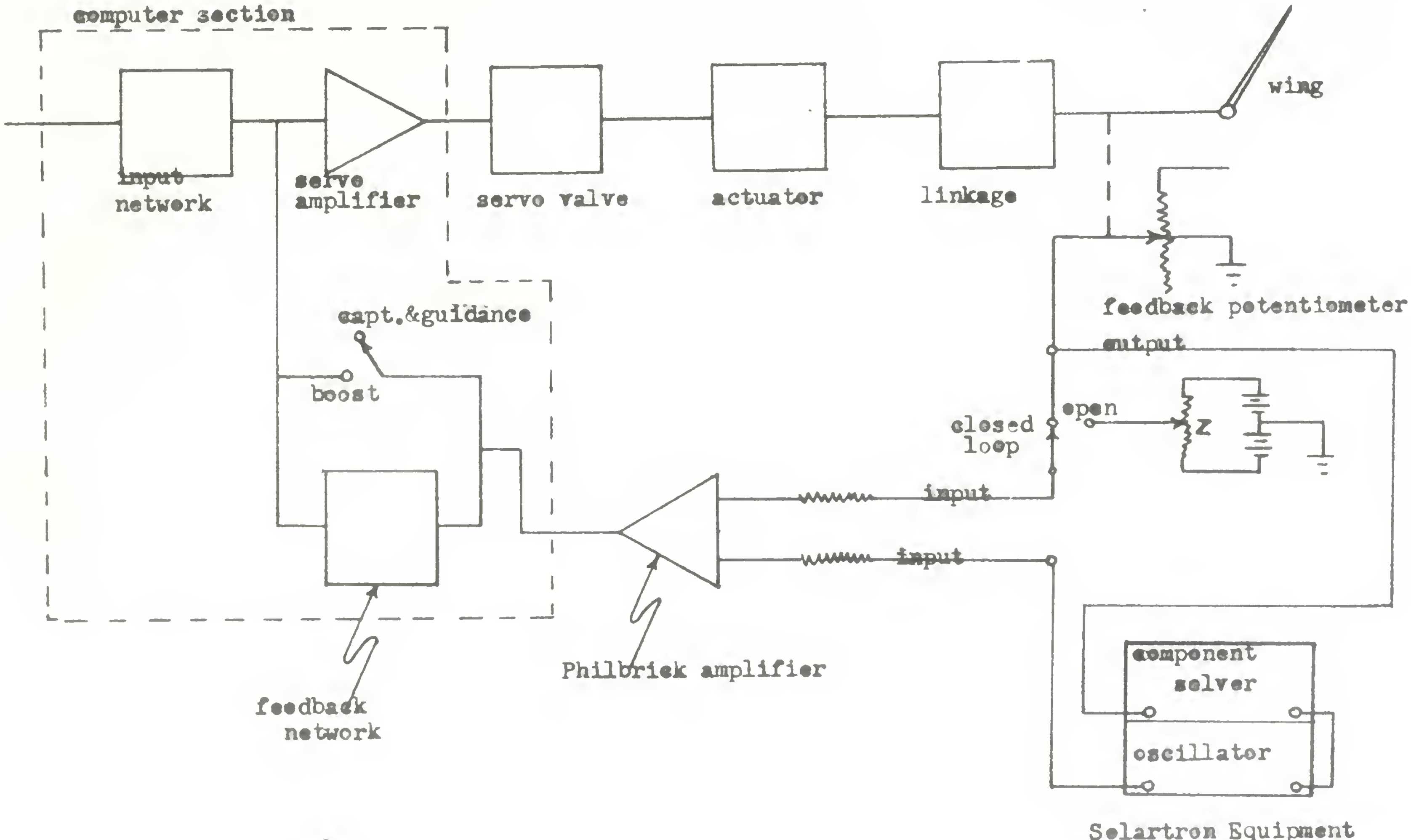
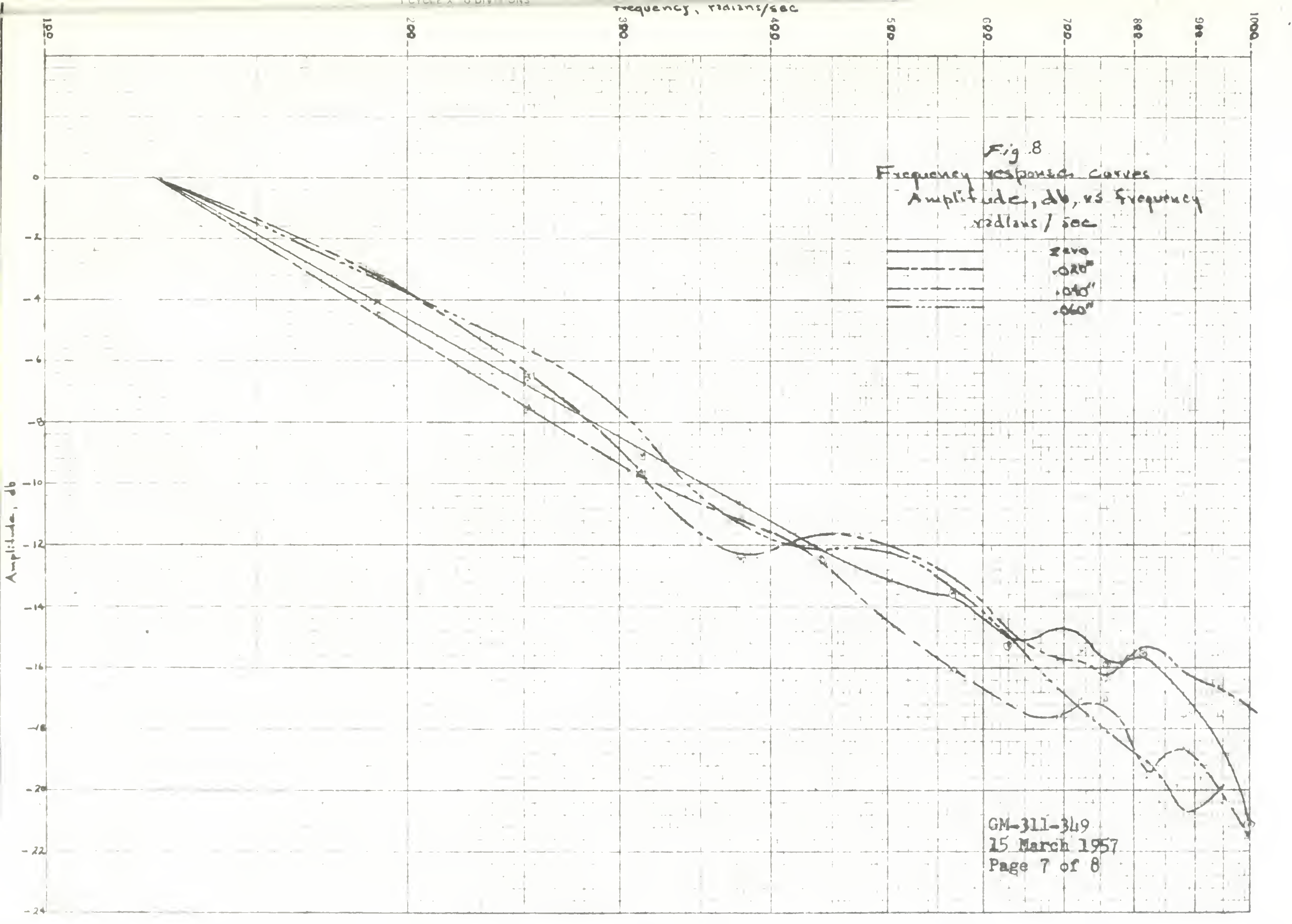
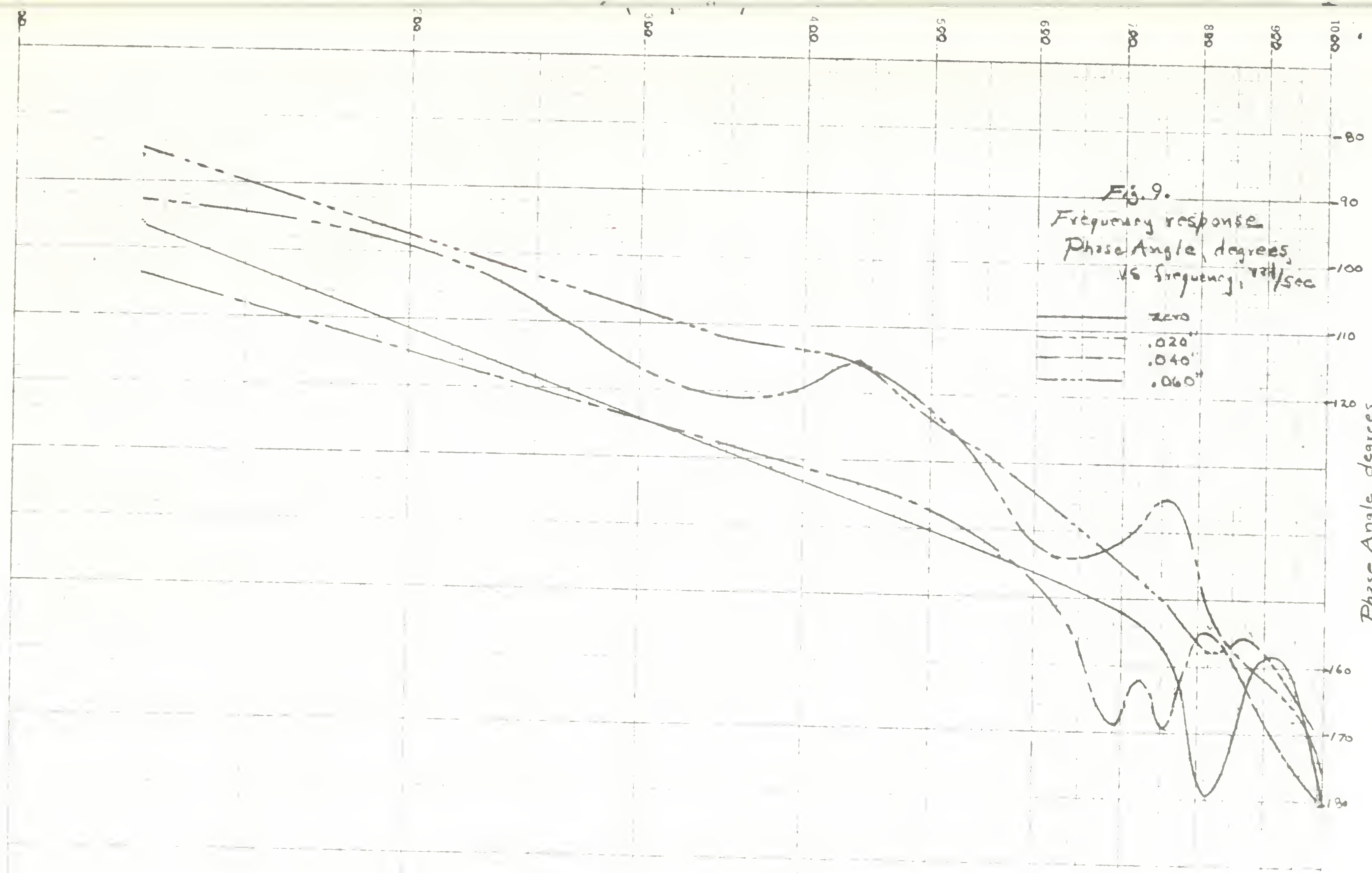


Fig.7 . Schematic of test equipment set-up


Frequency, radians/sec
100
200
300
400
500
600
700
800
900
1000
Amplitude, db
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
Fig 8
Frequency response curves
Amplitude, db, vs frequency
radians / sec
zero
.020"
.040"
.060"



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